STRENGTHENING THE INTEGRITY, CREDIBILITY, AND EFFECTIVENESS OF TERRASOS BIODIVERSITY UNITS THROUGH THE APPLICATION OF DISTRIBUTED LEDGER TECHNOLOGY

TERRASOS

Tebu™ TERRASOS BIODIVERSITY UNIT™

REGEN NETWORK

ISBN: 978-958-53968-4-5

AUTHORS

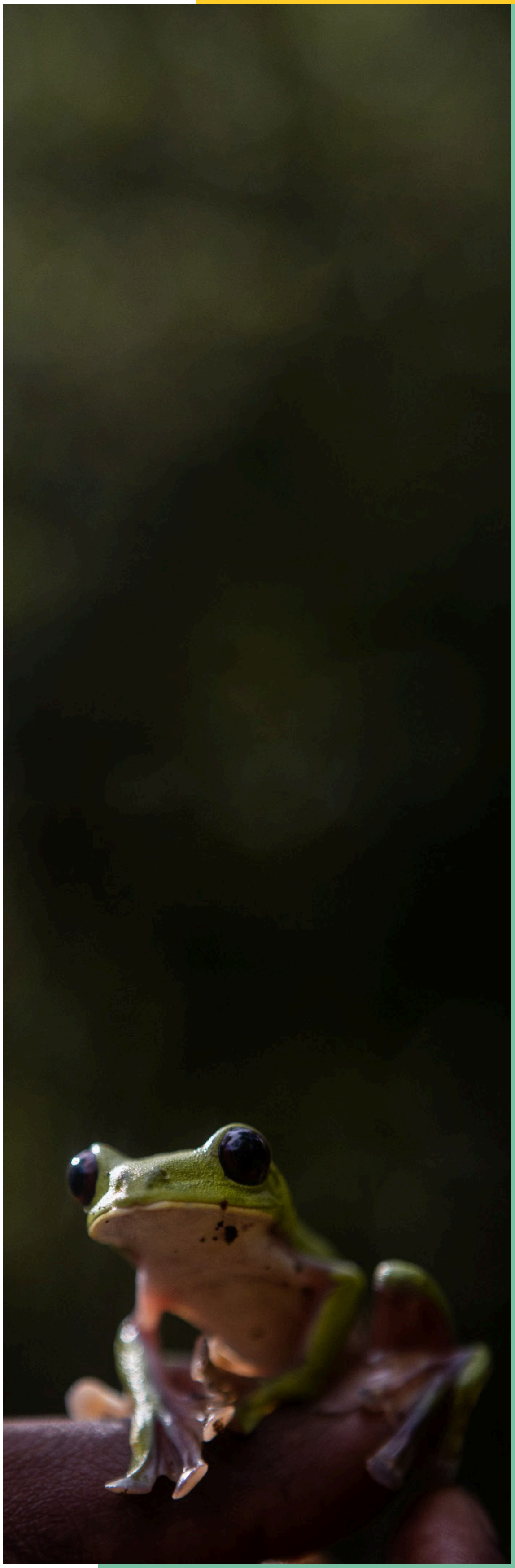
Sam Bennetts
Cory Levinson
Austin Wade Smith
Gregory Landua
Mariana Sarmiento
Francisco Gómez
María Lucía Rodríguez

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION



For over two decades, environmental credits have served as a vital tool in addressing climate change and biodiversity loss by translating broad environmental commitments into actionable outcomes. Environmental credits provide a quantifiable measure of positive ecological interventions, allowing organizations to gauge progress of environmental initiatives and direct financial support to projects. In regulated biodiversity markets, credits facilitate the implementation of conservation projects by creating a shared unit of account that government agencies and institutions can use to quantify contributions needed to invest in ecological well-being and offset impacts of human development. More recently, interest in voluntary biodiversity crediting schemes have surged as international initiatives like the post-2020 Global Biodiversity Framework continue to underscore the need for effective conservation strategies (Open-ended Working Group on the Post-2020 Global Biodiversity Framework, 2022). As these new markets are established, the need to create robust systems which ensure the integrity and efficacy of credits becomes increasingly important.

Responding to these growing demands, Terrasos, with the support of Partnership for Forests, created the Protocol for Issuing Voluntary Biodiversity Credits, which introduced a new process for the issuance and management of biodiversity credits in voluntary markets. The Protocol aims to foster a market environment rooted in trust and inclusive participation by providing criteria for designing and establishing credits based on principles of transparency, auditability, and long-term sustainability. The Terrasos biodiversity unit, or Tebu, represents $10m^2$ of preserved and/or restored ecosystem managed by a group of actors who provide the technical, financial, and legal oversight needed to guarantee quantifiable biodiversity outcomes (Sarmiento et al., 2022).

To uphold the integrity and reliability of Tebu, the Protocol leverages Distributed Ledger Technology (DLT): digital systems that use cryptographic techniques to create transparent, traceable, and immutable records of data and transactions across a decentralized network of computers. DLT ensures robust end-to-end tracking of Tebu by providing an unbroken chain of custody from creation to retirement, mitigating issues like fraud, double-counting, and the reselling of the same credit. Project information stored on DLTs creates a digital audit trail of data underpinning claims, allowing each Tebu's impact on biodiversity to be accurately documented, verified, and preserved by participating stakeholders to enhance oversight and increase trust throughout the system. Moreover, DLT provides the ability to track project and protocol governance to promote more transparent and inclusive decision-making processes.

This paper serves as a foundational guide for integrating DLT into the design and operation of voluntary biodiversity markets. By detailing the practical applications of DLT in enhancing the integrity, transparency, and governance of the Tebu Protocol and credit, this document highlights the potential these emerging technologies have in fostering trust and confidence in actions taken to protect and enhance natural ecosystems. The principles, philosophies, methods, and technical insights proposed herein provide guidance to project developers, policy makers, registries, verifiers, and on-the-ground communities interested in leveraging DLT to promote the development of high-quality biodiversity projects. Ultimately, this paper aims to catalyze the creation of accessible, efficient, and equitable biodiversity markets that enable better conservation outcomes and establish new standards for the role of technology in driving positive environmental change.

2. BACKGROUND

2.1 *Biodiversity Credits, Units, & Environmetal Commitments*

A biodiversity credit is a certificate that represents a measured and evidence-based unit of positive biodiversity outcome, durable and additional to what would have otherwise occurred. The unit underpinning a credit provides a quantifiable measure of outcomes, defined as reduction in threats to biodiversity, prevention of anticipated declines in biodiversity, or uplifts in biodiversity resulting from project interventions such as ecological restoration (Biodiversity Credit Alliance, 2024).

Biodiversity units often incorporate a geographic area component and several metrics that describe habitat conditions, such as ecosystem structure, function, and composition to establish a coherent unit of account. The specific metrics used to quantify biodiversity units often vary based on the ecosystem, conservation goals, and methods employed. Due to the complex nature of measuring biodiversity and the specific requirements of different ecological interventions, there are a wide range of definitions for what constitutes a biodiversity unit. A recent study by Gradeckas, as of June 2024, indicates that over 52 organizations are actively developing or operating biodiversity crediting schemes with similar yet distinct definitions of what constitutes a unit.

Despite this variability, biodiversity credits provide a structured mechanism to convert conservation and restoration efforts into terms recognizable by financial markets, thereby facilitating the practical application of voluntary, or mandated environmental commitments.

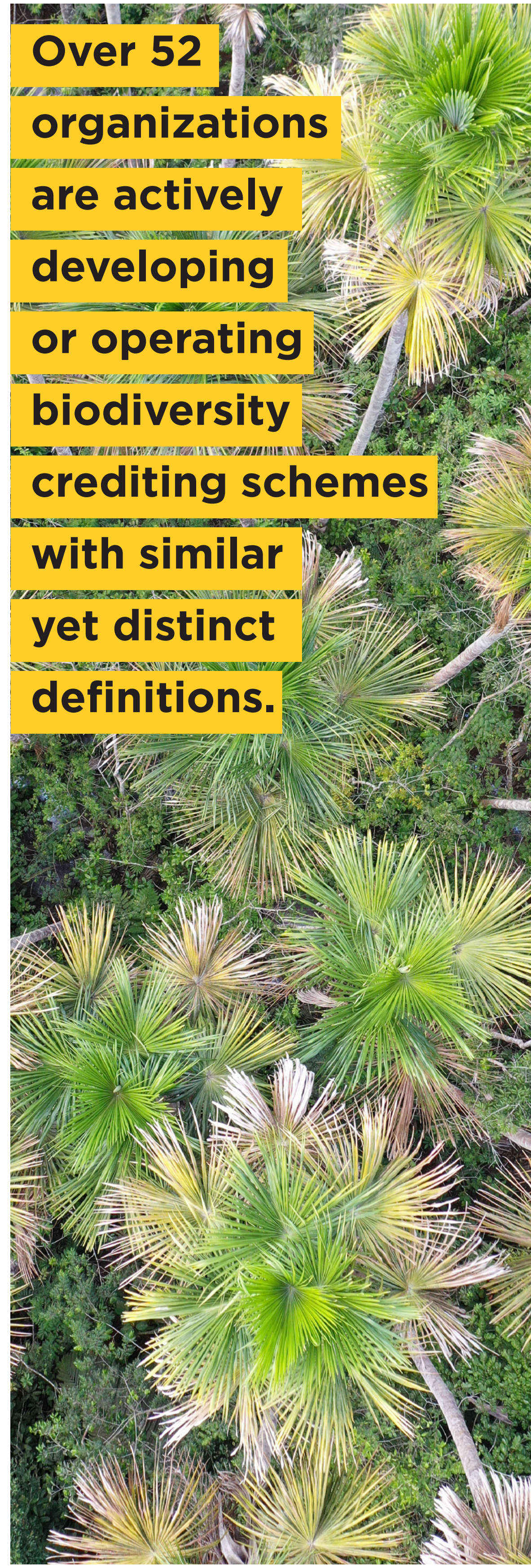
2.2

Crediting Protocols in Biodiversity Markets

Crediting protocols form the foundation of biodiversity markets, offering a structured approach to govern the creation, verification, and management of biodiversity credits. These comprehensive frameworks guide market participants through the intricate process of credit development, delineating clear roles and responsibilities for project developers, landowners, auditors, and registry operators working to translate conservation activities and biodiversity outcomes into clear, standardized units.

Crediting protocols define methods to assess project eligibility, measure additionality, collect data, submit monitoring reports, and verify claims. They ensure the permanence of biodiversity outcomes by specifying risk management strategies, such as buffer pools and insurance mechanisms, and establishing rules for credit issuance, transfer, and retirement. Many protocols also outline processes to leverage digital technologies, such as registry systems, to enhance transparency, traceability, and real-time access to project data, while reducing the risk of double-counting.

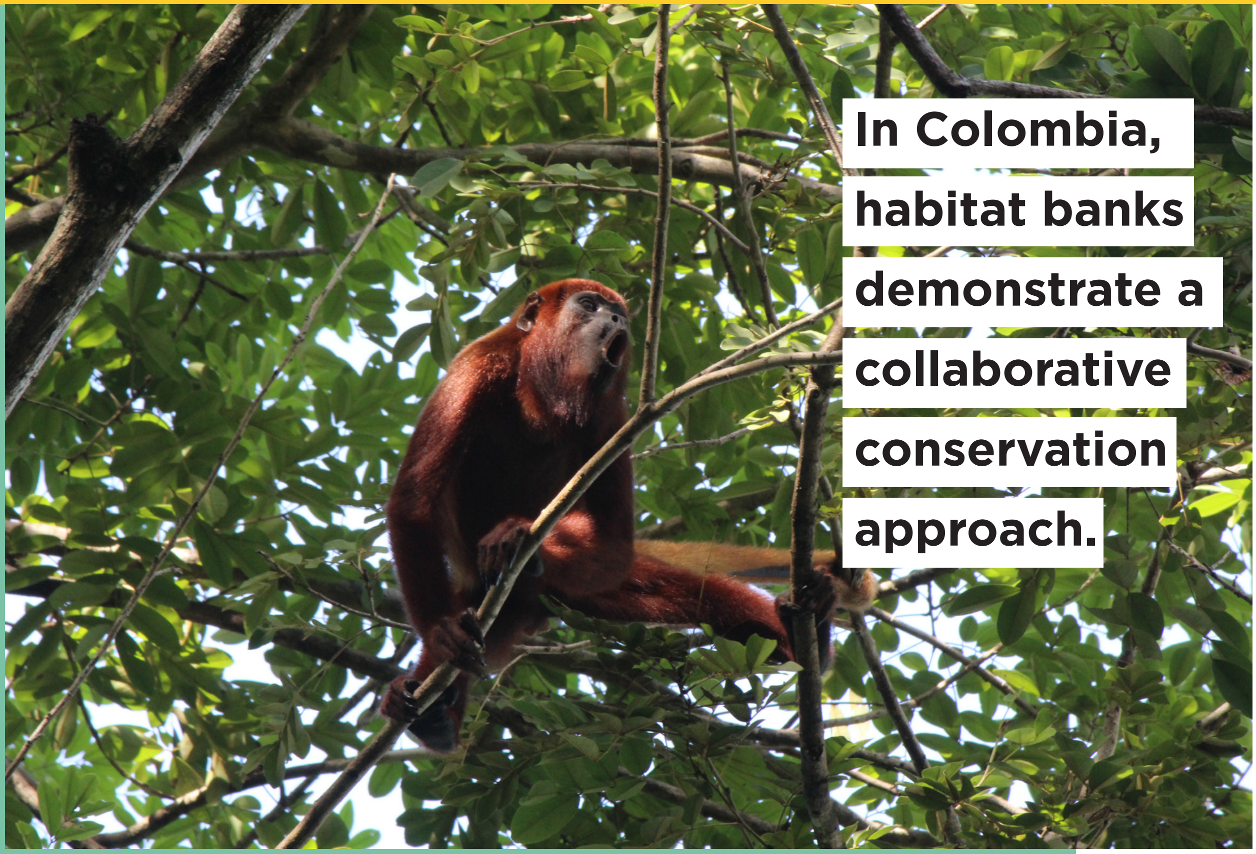
The establishment of a common language and standardized set of rules enhances trust and accountability in biodiversity markets. Investors can more easily compare and evaluate diverse conservation projects, leading to increased capital flow into biodiversity initiatives. These frameworks not only streamline credit creation and verification but also catalyze market growth, fostering innovation in biodiversity conservation financing and encouraging broader participation across sectors.



2.3 *Credits in Policy Regulated Biodiversity Markets*

In policy-regulated biodiversity markets, credits serve as a mechanism to align economic development with national conservation goals through established regulatory frameworks. These credits allow organizations to fund conservation efforts in exchange for development rights that impact specific ecosystems. In New South Wales (NWS), for instance, the Biodiversity Offsets Scheme (BOS) permits landowners to create and sell biodiversity credits to organizations needing to offset environmental impacts from projects that disrupt natural habitats (State of New South Wales (Department of Climate Change, Energy, the Environment and Water), 2011).

In Colombia, habitat banks demonstrate a collaborative conservation approach where developers and landowners pool resources to create large, continuous tracts of land that support ecological connectivity and restore diverse ecosystems (Sarmiento et al., 2018). Registered with the Ministry of Environment and Sustainable Development of Colombia and managed by local operators, these habitat banks operate under a pay-for-success model which upholds principles of integrity by selling credits to compliance-obligated developers and voluntary buyers after outcomes have been rigorously measured and verified.



2.4 *Credits in Voluntary Biodiversity Markets*

Voluntary biodiversity markets have experienced significant growth in the last few years, reflecting a growing interest from corporations, non-profits, and individuals to help address the more than $7 trillion American dollars funding gap for nature protection and uplift identified by the United Nations Environment Programme (UNEP, 2023). These markets support a broader array of conservation and stewardship activities that might not qualify for, or have access to, traditional regulatory frameworks. Credits in these markets facilitate financing of projects that yield measurable biodiversity benefits, such as reforestation, wetland restoration, conservation of ecosystem services, and sustainable agriculture practices.

The flexibility of voluntary markets promotes rapid innovation in methodology development and credit design, allowing for the integration of cutting-edge ecological science and technology to create impactful and sustainable conservation strategies (Pollination, 2023). This adaptability also encourages more participation from stakeholders, such as Indigenous communities, local landowners, and small conservation groups, who can directly engage with buyers and end users to co-create solutions which uphold principles of integrity and trust.

Despite their rapid development, voluntary biodiversity markets are still new, underscoring the need to establish processes and standards that ensure both environmental integrity and economic viability. As these markets mature, however, crediting schemes developed in the voluntary sector can inform government-sponsored programs to expand the effectiveness of conservation efforts and enhance the overall impact of biodiversity credits.

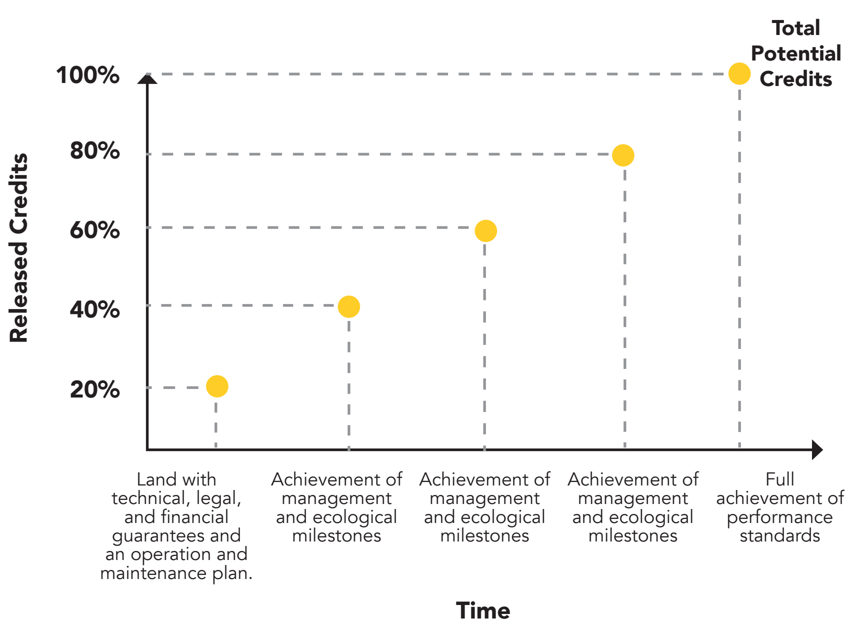
3. TERRASOS PROTOCOL FOR ISSUING BIODIVERSITY UNITS

3.1 *The Tebu Protocol*

The Terrasos Protocol for Issuing Biodiversity Credits (hereinafter referred to as the Protocol or Tebu Protocol) seeks to support the development of high-quality biodiversity projects by offering a structured pathway for registering, quantifying, and issuing biodiversity credits. The Terrasos Biodiversity Unit, or Tebu, represents 10m2 of /a preserved and/or restored ecosystem, technically, financially, and legally managed by a project operator to achieve quantifiable biodiversity gains for at least 20, and up to 50, years (Sarimento, et al., 2022). Tebu generate long-term value for ecosystems, communities, and investors by ensuring outcomes represent real, measurable improvements in habitat quality, ecosystem function, and community engagement.

The structured credit release schedule used by the Protocol, shown in Figure 1, guarantees transparency and accountability of registered projects by only releasing units upon successful achievement of ecological and management milestones, verified by independent third parties. Project operators can modify the release schedule and the number of credits issued to accommodate the dynamic and complex nature of these multi-stakeholder projects. This staged and flexible approach, coupled with the detailed method to quantify Tebu on both performance and stewardship metrics, promotes ecosystem resilience by rewarding community evolving state of the project, favoring those which actively improve conditions in threatened habitats.

Figure 1. Tebu Protocol Credit Release Schedule



3.2 *Principles for Issuing Terrasos Biodiversity Units*

The Tebu Protocol draws inspiration from existing ecological crediting schemes and conservation frameworks and expands upon their successes with a robust set of principles designed to enhance the integrity, transparency, and inclusivity of biodiversity credits and the processes used to create them. These guiding tenets, outlined in Table 1, serve as both a blueprint and benchmark for the development of high-quality conservation projects which are additional, scientifically rigorous, and aligned with broader environmental management strategies (Sarimento, et al., 2022).

Incorporating these principles into the creation and management of Tebu systematically advances the clarity, accountability, and accessibility of the entire crediting process, effectively addressing key challenges such as disputed claims, complex verification processes, traceability of credits, and the equitable distribution of resources. This strategic approach not only builds trust among stakeholders but also ensures that conservation projects deliver substantial and ongoing ecological benefits to encourage broader participation in the emerging voluntary market.[1]

Table 1. Core Principles of the Protocol for Issuing Biodiversity Credits in Voluntary Markets

Principle	Description
Traceability	Projects must provide comprehensive access to information on the value chain and biodiversity claims data, including detailed results from monitoring actions.
Permanency	Projects m ust establish technical, administrative, financial and legal conditions that secure the continuity of the actions for at least 20 to 50 years.
Rigor	Projects must demonstrate analytical and scientific rigor by conducting all activities specified in the management plan with thorough, adaptive monitoring, which ensures the achievement of targeted outcomes.
Transparency	Projects must engage in public and open consultation procedures and offer full disclosure on the participants, their roles, client details, and pricing.
Additionality	Projects must produce verifiable conservation outcomes that exceed those that would occur without the interventions and contribute to the reduction of investment, institutional, technological, environmental, prevailing practices, property and social barriers, among others.
Complementarity	The strategies and actions of projects should align with and support the environmental planning and management instruments of the territory, as well as national or regional conservation priorities.
Applicability	The protocol must be designed for practicality and flexibility to facilitate its implementation across various environmental, social, and economic contexts.

[1]For more information: https://www.terrasos.co/wp-content/uploads/biodiversity-units-protocol-version-4-0-english.pdf

4. REGISTRY SYSTEMS IN BIODIVERSITY CREDITING SCHEMES

4.1 *Registry Systems & Crediting Protocols*

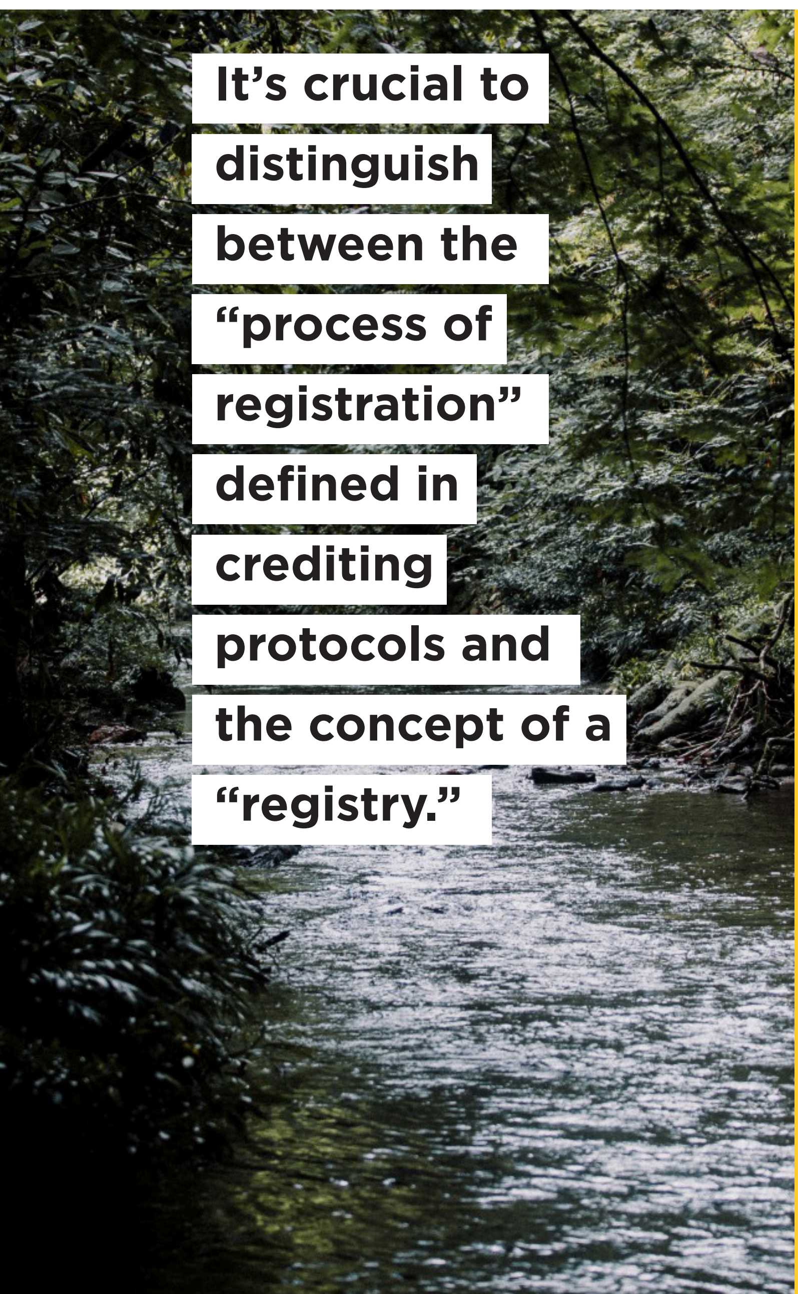
Registry systems function as the digital backbone of biodiversity markets, providing a comprehensive database to record, verify, and track the lifecycle of biodiversity credits. These systems ensure transparency, traceability, and accountability by facilitating the structured input of data, management of transactions, and tracking of credit ownership—from issuance through transfer and retirement. By storing detailed information about projects, including registration documents, ongoing ecological monitoring data, and verification reports, these systems create a transparent and accessible digital audit trail of the credit creation process.

In the context of biodiversity crediting programs, it's crucial to distinguish between the "process of registration" defined in crediting protocols and the concept of a "registry." Crediting protocols serve as the guiding framework that defines the process, roles, responsibilities, and reporting requirements of various stakeholders involved in credit creation, trading, and financing. In contrast, registry systems, or "registries", provide the technical means to implement these functions, acting as independent and authoritative sources of truth that hold actors accountable to their actions by providing a digital record of their contributions.

This clear delegation and tracking of data and actions ensure that each party understands and fulfills their obligations. It creates a system of checks and balances where different actors can verify and validate each other's work, reducing the risk of errors or fraud and mitigating issues like double counting to foster trust and transparency within the market.

4.2 *Design of the Tebu Registry System*

The Tebu Protocol outlines essential principles and processes for registry platforms to support the integrity of Tebu. It calls for a transparent, traceable system that improves compliance efficiency, facilitates stakeholder coordination, and serves as a repository ensuring Tebu represents genuine and additional biodiversity gains. This section introduces the key features required for the Tebu Registry System to meet these requirements and provide a robust technological foundation for the emerging biodiversity credit market.



It's crucial to distinguish between the "process of registration" defined in crediting protocols and the concept of a "registry."

Key design features of the Tebu Registry System include:

- **Credit Lifecycle Management:** The system recognizes the characteristics and final property of issued credits, ensuring clear ownership and transfer records throughout the credit lifecycle. It includes an integrated accounting module to track credit inventories precisely, supporting efficient market operations. Each biodiversity credit is assigned a unique serial number, ensuring individual tracking and preventing double-counting.
- **Role-based Access Control and Responsibility Tracking:** The registry delineates the roles and responsibilities of each actor, providing visibility into who participated in each stage of the process. It implements role-based access controls, ensuring that only authorized persons can view specific information, with appropriate access guaranteed according to each user's role. This feature balances transparency with data security while accommodating different user permissions based on their role in the biodiversity crediting mechanism.

- **Data Security & Confidentiality:** The system incorporates robust security measures to protect sensitive information, aligning with the trust-building objectives of the Tebu Protocol. It includes protocols to prevent leaks, fraud, and manipulation of information, ensuring the overall integrity of the data within the system.
- **Information Integrity & Immutability:** The registration platform employs mechanisms that attribute authorship of information with absolute certainty. These mechanisms prevent unauthorized modifications, supporting the integrity principle of the protocol and ensuring that once data is entered, it cannot be altered without proper authorization and documentation
- **Traceability of Information:** The system tracks and records the complete history and trajectory of project information and Biodiversity Credits, from issuance to cancellation. This feature supports the traceability principle outlined in the Tebu Protocol, allowing for a comprehensive audit trail of all activities within the system.
- **Public and Private Sections:** The registry platform maintains both public and private sections, with clear conditions for disclosure of information based on the requirements of each dataset and document. This ensures that sensitive information is protected while still providing necessary transparency for public scrutiny and market confidence.

5. INTEGRATION OF DIGITAL LEDGER TECHNOLOGY IN BIODIVERSITY MARKETS

5.1 *Understanding Digital Ledger Technology*

Distributed Ledger Technology (DLT), such as blockchain, refers to digital systems that use cryptographic techniques to create transparent, traceable, and immutable records of data and transactions across a decentralized network of computers. This innovative approach to data management represents a significant departure from traditional centralized database systems, offering enhanced security, transparency, and efficiency in recording and verifying information.

DLT operates on a network of nodes, each maintaining an identical copy of the ledger. The network of nodes must validate and agree on new information before adding it. This consensus mechanism ensures integrity and consistency of data across the entire system. In blockchain systems, this information is organized into "blocks." Each block typically contains a timestamp, transaction data, and a reference to the previous block, creating an unbroken chain of information. This structure allows for easy verification of data integrity and provides a clear audit trail of all changes made to the ledger. Once recorded, it becomes nearly impossible to alter or delete information, creating a tamper-resistant record of all transactions and data entries.

User actions on blockchain networks generate transactions, which represent various activities, such as issuance and management of digital assets, like tokens or credits, transference of between user accounts, storage of datasets for secure record-keeping, or updates to metadata associated with tracked entities.

DLT utilizes several key technologies to ensure data integrity and security:

1. **Cryptographic Hash Functions:** Complex mathematical algorithms that generate unique digital "fingerprints" for each piece of data. Like a machine converting any information into uniquely identifiable codes, they create a seal that breaks if tampered with, making data alterations obvious and ensuring recorded information remains unchanged.

2. **Merkle Trees:** Data structures that allow for efficient and secure verification of large datasets. Functioning like a family tree for data, they allow checking individual branches without examining the entire tree, facilitating privacy-preserving verification of specific information without revealing the entire dataset.

3. **Smart Contracts:** Self-executing agreements encoded into the system that automatically enforce predefined terms when certain conditions are met, much like a vending machine that dispenses a product when the correct amount of money is inserted.

4. **Digital signatures:** Cryptographic mechanisms that ensure the authenticity and integrity of a message or transaction. It works like a handwritten signature on a document, but much more secure, since it uses private keys to digitally sign data, generating a unique fingerprint that can only be verified with the corresponding public key. Any alteration in the data invalidates the signature, ensuring that the information has not been manipulated during its transmission.

Together, these technologies create a decentralized and distributed computational infrastructure that allows a network of participants to share the responsibility of upholding data integrity, ensuring secure, transparent, and verifiable transactions and fostering trust and reliability in applications like biodiversity crediting schemes.

5.2 *Advantages of Distributed Ledger Technology in Biodiversity Markets*

Distributed Ledger Technology (DLT) offers transformative advantages for biodiversity markets, primarily through its capacity to serve as a robust registry system. This technology adeptly manages the complexities of verification, governance, data management, and stakeholder engagement, all crucial for ensuring activities lead to real and measurable biodiversity outcomes. The blockchain-based system provides an immutable record of all transactions and project data, enabling transparent verification by third parties and ensuring the integrity of biodiversity credits, while offering a scalable solution for project developers, verifiers, and credit buyers. The immutability of blockchain technology prevents manipulation and fraud, while decentralization promotes a balanced distribution of power among participants.

5.2.1 *Asset Tracking and Management of Credits*

DLT significantly enhances the tracking and management of biodiversity credits, transforming them into digital tokens on a blockchain. This system not only records each credit's ownership and transaction history on an immutable ledger but also secures the metadata, making the entire lifecycle of the credit clear and tamper-proof. Such rigorous transparency and the ability to audit records easily increase trust among market participants, effectively reducing fraudulent activities and preventing double-counting.

By employing credits as tokens, DLT enables secure, verifiable transfers between users, thus creating a dynamic and fluid market. Participants have the flexibility to buy, sell, or trade credits in alignment with their environmental goals, contributing to a more active and engaged marketplace. Additionally, the system supports the definitive retirement of credits, which are removed from circulation once a user claims the associated social benefits, ensuring the integrity of each transaction.

The clear, reliable nature of transactions and the guaranteed impact of each credit make the market more appealing to investors and environmental groups. As more entities participate, the scale of conservation efforts increases, driving more significant and effective environmental improvements. This broad participation enhances the overall impact of biodiversity markets, turning them into powerful tools for global conservation.

5.2.2 *Evidence and Auditability of Credits*

DLT provides a powerful foundation for managing evidence and auditing claims within biodiversity markets. This technology ensures that all transactions and associated data are transparent, verifiable, and secure, thereby enhancing trust and credibility in the environmental impacts of conservation projects.

DLT safeguards the integrity and accessibility of credit information by enabling project participants to register datasets on the network. This process, known as "anchoring," involves storing timestamped records of data alongside unique identifiers. Should the data be altered in any manner, the unique identifier—or content hash—would change, thereby documenting any modifications and preserving the original data's integrity. This level of transparency empowers stakeholders, including buyers, regulators, and the public, to independently verify the authenticity of claims made by project developers and monitors.

Beyond anchoring, DLT facilitates the attesting of data, where users provide unique digital signatures that certify the accuracy and authenticity of the data. Attesting plays a critical role by enabling individuals or organizations to endorse the validity of data actively. These attestations serve as a powerful tool for building trust, as they ensure that each piece of evidence is not only recorded but also formally acknowledged by a credible source. This verification process is crucial in establishing the reliability of environmental claims and in fostering accountability among all parties involved.

The combination of cryptographic hash functions and digital signatures through DLT underpins the integrity and authenticity of the submitted data. By linking each piece of evidence to the user who submitted it, DLT creates a clear and detailed audit trail that enhances accountability. Furthermore, the decentralized nature of DLT distributes the evidence across a network of nodes, greatly enhancing the data's resilience to loss or manipulation. This feature is especially valuable in biodiversity markets, where the credibility of environmental claims is paramount. This decentralized verification mechanism not only secures data against tampering but also ensures that it withstands scrutiny, maintaining its value as a reliable asset in promoting and protecting biodiversity.

Table 2. Definitions for anchoring and attesting

Term	Definition
Anchoring	The process of registering a dataset or claim on a blockchain network, creating a and tamper-proof of that ensures the claim's integrity and immutability.
Attesting	The process of an individual or organization attaching their digital signature to a claim, thereby endorsing its accuracy and authenticity. The attestor may be the original author of the claim, or a 3rd party such as a verifier.

5.2.3 Governance and Decision-Making Processes

Transparency and accountability in governance play critical roles in maintaining the integrity of biodiversity crediting schemes. DLT offers a robust framework for managing and recording governance actions around the crediting process of each specific project transparently and traceably. This level of transparency allows stakeholders to verify actions and outcomes, boosting trust and strengthening the credibility of conservation efforts.

Moreover, DLT provides functionality which allows users to co-govern actions taken on the network. By using blockchain-enforced decentralized governance structures, stakeholders can implement a system of checks and balances whereby users must propose, vote on, and implement changes to the crediting protocol, or mutually approve registration or issuance processes. This participatory approach ensures decisions reflect the collective input of all parties involved and enhances the adaptability and responsiveness of governance to emerging challenges and opportunities, while ensuring no one party has undue control.

6. TECHNICAL ARCHITECTURE FOR THE TEBU REGISTRY SYSTEM

6.1 *Crediting Protocol Architecture*

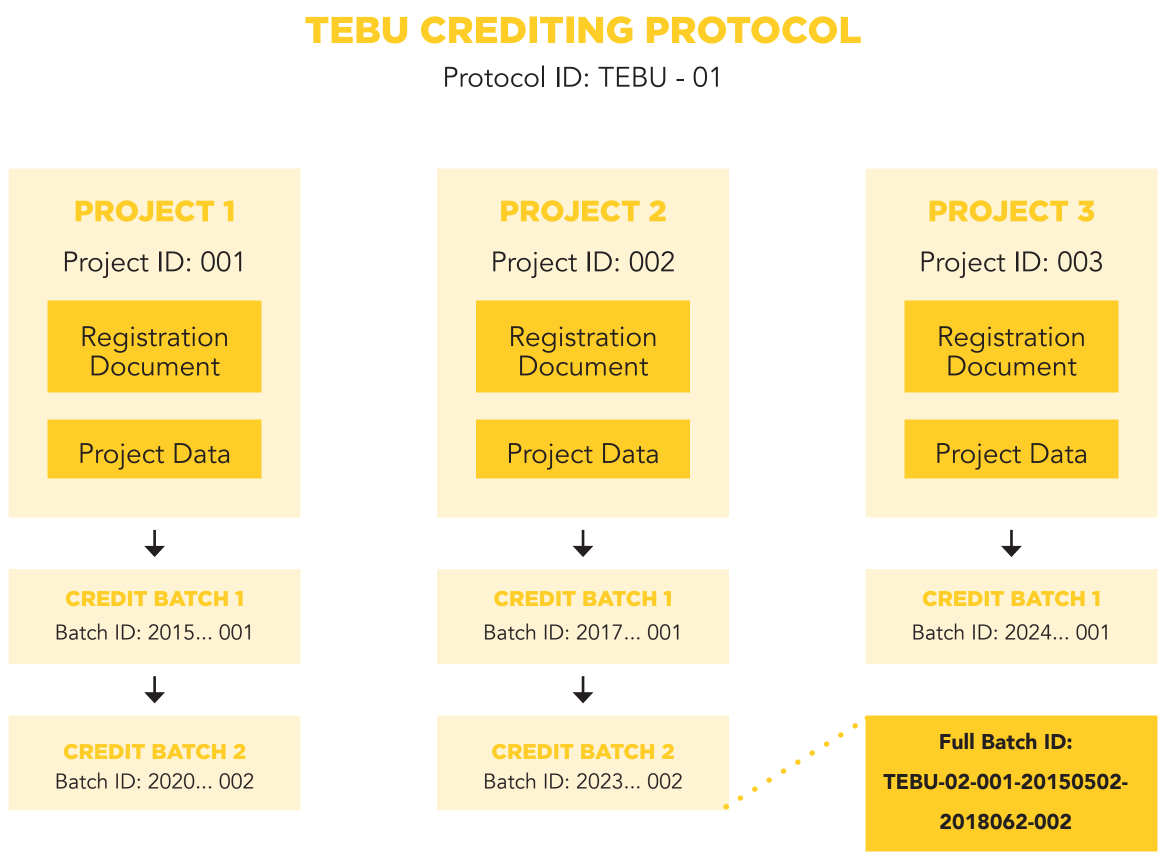
The Tebu Protocol leverages Regen Ledger's blockchain infrastructure as its registry system, utilizing the ecocredit module to implement project registration and credit issuance processes. The ecocredit module provides a robust, transparent, and efficient framework for managing biodiversity credits. At the core of this system lies the concept of Credit Classes, which serves as the primary abstraction for representing the Tebu Protocol on Regen Ledger. The Tebu Credit Class, identified by a unique code, acts as a distinct conceptual container within the registry system, allowing users to register projects and issue credits under the given crediting protocol. The system facilitates the registration of individual biodiversity projects, assigning each a unique identifier and designating a Project Admin to oversee the associated blockchain data (Ecocredit Module Documentation).

Table 3. Key Components of the Tebu Protocol architecture on Regen Ledger

Component	Definition	Identifier
Credit Class	The primary abstraction for representing the Tebu Protocol on Regen Ledger, the Credit Class is a distinct conceptual container within the registry system allowing users to register projects and issue credits under the given crediting protocol.	TEBU-01
Credit Type	The primary unit of measurement for credits issued under a given Credit Class. In the case of Tebu, this unit is $10m^2$ of a preserved and/or restored ecosystem.	TEBU
Project	The primary abstraction for representing an individual biodiversity project on Regen Ledger. Projects registered in a Credit Class have a unique identifier, and their associated blockchain data is managed by a designated Project Admin.	TEBU-01-001
Credit Batch	A discrete quantity of credits issued to a project upon reaching specified milestones. Each credit batch has a unique identifier corresponding to the Protocol ID, Project ID, milestone reporting dates, and the batch number. Credit batches associated with the project track the total number of active (tradable and retired) and canceled credits.	TEBU01-001-20210101-20220101-001
Credits	Individual quantities of credits within a batch held by users in a tradeable or retired state. Tradeable credits can be transferred, listed for sale, or retired by the owner. Owners may be project admins, or credit purchasers, or specially designated accounts managed by the protocol.	

Credits issued using a specific and pre-defined Credit Type, which denotes the primary unit of measurement. For the Tebu Protocol, this unit represents 10m2 of a preserved and/or restored ecosystem, denoted simply as TEBU. Credit issuance occurs through a batch process, where discrete quantities of credits are issued to a project upon reaching specified milestones. Each Credit Batch receives a unique identifier that incorporates the Protocol ID, Project ID, milestone reporting dates, and batch number (e.g., TEBU01-001-20210101-20220101-001). These batches track the total number of tradeable, retired, and canceled credits associated with the project. Figure 1 depicts the relationship between crediting protocols, projects, and credit batches in the Tebu Protocol architecture.

Figure 2. Technical Architecture of the Tebu Protocol using the Regen Ledger Ecocredit Module



Individual credits within a batch can exist in either a tradeable or retired state. Tradeable credits can be transferred, listed for sale, or retired by the owner, who may be project admins, credit purchasers, or specially designated accounts managed by the protocol. This flexible system ensures that credits can be efficiently managed and tracked throughout their lifecycle, from issuance to retirement.

6.2 *Roles of Project Actors and the Registry System in the Project Registration & Credits or Units Issuance Process*

The Tebu Protocol defines three main roles to operate a credit class: Credit Class Administrators, Registry Agents, and Project Administrators. Each role carries specific technical permissions within the ecocredit module, ensuring a clear delineation of responsibilities and maintaining system integrity. Additionally, the protocol recognizes a fourth crucial role: the Verifier. These roles, each with distinct responsibilities, form the core operational structure of the Tebu Protocol.

Credit Class Administrators, technically referred to as Credit Class Admins in the system, possess the highest level of authority within a credit class. They govern the crediting protocol and have the technical ability to appoint Registry Agents and manage Protocol metadata stored on Regen Ledger. Registry Agents, termed "issuers" in the technical documentation, have the technical ability to register projects and issue credit batches to registered projects in accordance with the credit release schedule. Project Administrators, or Project Admins, manage individual projects within the system. Their technical permissions allow them to submit various project-related documents and manage project metadata stored on Regen Ledger. In addition to their technical abilities, each of these actors has other responsibilities as indicated in Table 4.

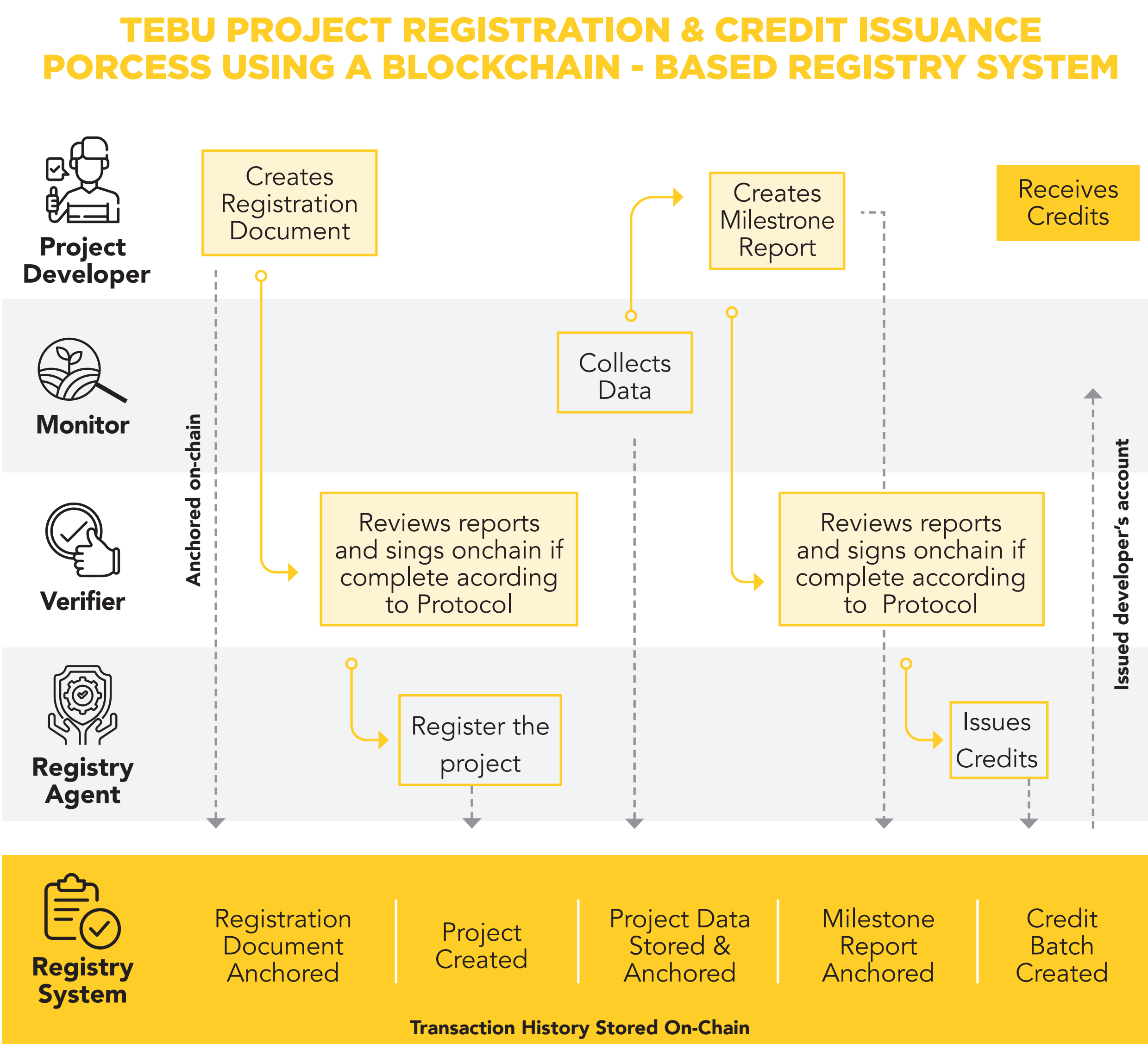
Table 4. Roles of Key Actors in the Project Registration and Credit Issuance Process

Actor	Role definition
Credit Protocol Administrator	**a)** Technically manage the list of approved Registry Agents who can register projects and issue credits within the Protocol **b)** Managing on-chain metadata for the Credit Class **c)** Managing Tebu Protocol governing body, identifying and distributing responsibilities between entities
Project Administrator	**a)** Submitting project plan, monitoring reports, verification reports, and supplemental documentation for project registry. Ensuring correctness of documentation submitted **b)** Main point of contact with the registry once a project has been accepted **c)** Responsible counterparty to manage and distribute issued credits **d)** Uploading project metadata
Registry Agent	**a)** Check for completeness of core documents, such as the registration document and verification reports, and supplemental datasets **b)** Register project according to proper completion of activities as outlined in the Tebu Protocol and approval of the verifier **c)** Issue credit batches to registered projects according to credit release schedule and approval of the verifier
Verifiers	**a)** Evaluate the registration document and ensure compliance milestones, performance standards, release schedule **b)** Provide an independent audit of compliance milestones to ensure recovery of biodiversity before approving credit issuance **c)** Digitally sign data and core documents anchored on Regen Ledger to indicate approval of project registration and credit issuance processes

While not directly defined within the ecocredit module, Verifiers play a vital role in ensuring the integrity and credibility of the biodiversity crediting process. They can maintain an on-chain account and perform critical activities such as evaluating registration documents, providing independent audits of compliance milestones, and digitally signing data and core documents anchored on Regen Ledger. Verifiers ensure that the management of the Tebu occurs transparently and that their sale genuinely represents demonstrable gains in biodiversity.

Underpinning these roles, the registry system, implemented on Regen Ledger's, plays a crucial role in storing data and providing a digital audit trail of actions, activities, transactions, and data throughout the entire process (Figure 3).

Figure 3. Tebu Project Registration & Credit/Unit Issuance Process



In providing functionality for users to anchor references to data on the blockchain, the registry system allows actors to confidently verify the authenticity of documents they possess by comparing it against the hashed version on the blockchain. This immutable record facilitates clearer, quicker verification processes, helps resolve disputes, and streamlines the entire registration and issuance process.

6.3 *Credit Quantification & Issuance*

6.3.1 Credit Quantification

The Tebu Protocol employs a comprehensive methodology to quantify Voluntary Biodiversity Credits. Project developers assess the project area using four key differentiating factors: IUCN Ecosystem Threat Category, opportunities for ecological connectivity, project duration, and preservation and restoration actions. These factors, combined with the total project area, determine the potential number of credits a project can issue. Project developers record this quantification in the Registration Document, which a third-party verifier must then verify and approve through the selected registration platform before any credit release can occur. This process ensures that the quantification of credits is based on rigorous ecological assessments and aligns with the protocol's standards for biodiversity conservation.

6.3.2 Credit Release

The Tebu Protocol's Credit Release Schedule ensures that credits are issued gradually as conservation projects meet specific performance standards. This approach prevents the immediate release of all potential credits, instead tying credit issuance to demonstrable biodiversity outcomes.

Registry Agents release credits for sale only when projects achieve key management and ecological milestones, as outlined in the release schedule (Figure 1). The process involves several steps:

1. **Monitoring of Compliance and Performance of Ecological and Management Milestones:** Project owners, developers, and third-party monitors collect ecological data and compile monitoring reports, documenting progress towards biodiversity conservation goals and management objectives outlined in the registration document.
2. **Third-Party Verification:** A qualified independent verifier rigorously assesses the monitoring reports, confirming the accuracy of reported biodiversity outcomes and ensuring compliance with the Tebu Protocol's standards.
3. **Credit Issuance:** Upon successful verification, Registry Agents issue credits in discrete batches, each with a unique identifier, reflecting the validated ecological improvements and enabling transparent tracking of biodiversity gains.

Each credit batch receives a unique identifier that includes the Protocol ID, Project ID, start and end dates of the milestone monitoring period, and a batch ID (e.g., TEBU01-001-20210101-20220101-001) (Figure 4). Once recorded on the blockchain, this metadata becomes immutable, ensuring data consistency and reliability throughout the credit's lifecycle.

Figure 4. Credit Batch Identifier for Tebu Credits

CREDIT BATCH IDENTIFIER

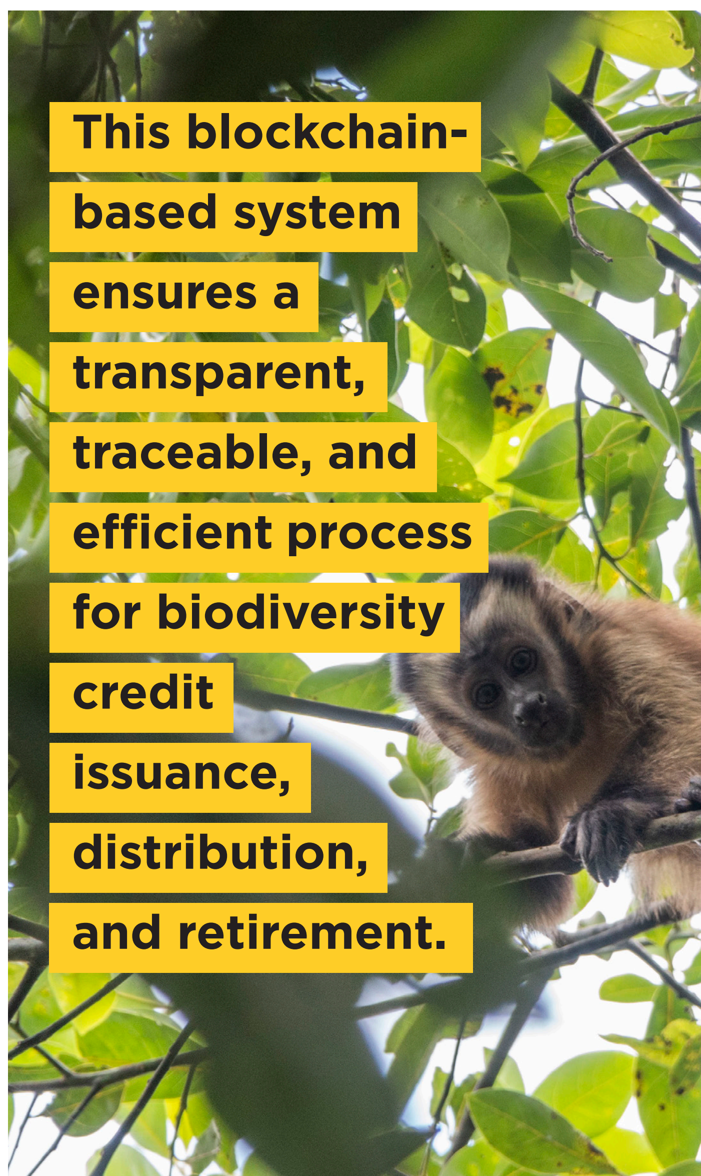
[Protocol ID] - [Project ID] - [Start Date] - [End date] - [Batch Number]
TEBU -01-001-20150502-20180602-002

Credits within the same batch are fungible with each other, meaning they can be traded interchangeably. However, credits from different batches, even within the same project, are non-fungible. This distinction allows for precise tracking of credit origins while still facilitating efficient trading within batches. It also enables the implementation of specific policies, such as insurance and buffer pools, tailored to credit batches or vintages.

6.3.3 Credit Distribution, Ownership, & Retirement

Once issued, Tebu are always held in account denoted by an on-chain address, designating credit ownership. Tradable credits are those that can be transferred between entities, facilitating a dynamic market where ecological gains can be bought and sold. Retirement of a credit, on the other hand, is a permanent action that signifies the credit has been claimed by a user, removing it from circulation. At any point in time, an owner of tradable credits can convert some or all their credits to a retired state.

The Regen Ledger ecocredit module provides marketplace functionality for credit trading, allowing sellers to list credits with specific price constraints and retirement options. The ledger records all transactions, ensuring transparent fund distribution and traceability. This blockchain-based system ensures a transparent, traceable, and efficient process for biodiversity credit issuance, distribution, and retirement.



7. TECHNICAL ARCHITECTURE FOR AUDITABLE DATA CLAIMS

7.1

Claims in the Tebu Protocol

The Tebu Protocol builds biodiversity credits on a foundation of ecological claims. These claims represent assertions about land management actions and ecological conditions, made by specific parties such as project developers, monitors, or verifiers. Claims range from high-level abstractions to low-level specifics, each supported by evidence collected through rigorous monitoring and observation. Each claim comprises key elements: the assertion itself, the claiming party, supporting evidence, and verification status.

Claims can be high-level and abstract (e.g., "the population density of the endangered species has increased by 20% over the past year"), or low-level and specific (e.g., individual timestamps and records of species monitoring events from a site visit). Claims are backed by evidence, consisting of data or information collected through monitoring and observations. This evidence substantiates the validity of claims about ecological states and management activities. Table 1 illustrates example ecological claims corresponding to measurement units and variables from the Tebu Protocol (Sarmiento et al., 2022).

Table 5. Examples of Ecological Claims in the Tebu Protocol

Group	Variable	Example Claim
Vegetation	Dissimilarity	The dissimilarity index between the restored area and the reference plot, measured using the Jaccard similarity index, is 0.35 as of May 1, 2024.
Vegetation	Species Richness	As of May 1, 2024, the species richness in the restored area includes 120 distinct species, indicating an increase in biodiversity since the initiation of restoration actions.
Fauna	Composition	The estimated population size of bats from the subfamily Phyllostomidae in the restored area is 500 individuals as of May 1, 2024, based on capture, mark, and recapture methodology.
Soils	Chemistry	The soil pH levels in the restored area are measured at 6.5 as of May 1, 2024, indicating optimal conditions for vegetation growth.
Soils	Physical	The percentage of organic matter in the soil of the restored area has reached 5% as of May 1, 2024, reflecting improved soil health and fertility.

Claims carry both objective and subjective elements. While the content often represents objective facts (e.g., soil pH levels), the claim itself embodies a subjective nature due to its authorship. The identity of the claim-maker holds equal importance to the claim's content, emphasizing the need for clear attribution in the protocol's infrastructure.

The Tebu Protocol structures its credit issuance process around a series of interlinked claims, ensuring that each credit represents a set of validated ecological improvements, providing a transparent and trustworthy mechanism for tracking and trading biodiversity gains. Project developers submit initial claims in their milestone reports, which they then review. Third-party verifiers subsequently validate these claims, adding another layer of credibility. This multi-step process necessitates a technical infrastructure that maintains durable and queryable links between claim content, authors, and verifiers.

7.2

Evidence & Claims Management for Tebu Projects

The Tebu Protocol implements a robust system for evidence and claims management using Regen Ledger's data module (Data Module). When project developers submit initial claims in registration documents and milestone reports, the data module anchors these claims with a tamper-proof timestamp. This anchoring effectively proves the claim's existence at a specific point in time using uniquely identifiable content hashes. Subsequently, when third-party verifiers validate these claims, they can attest to the anchored data. This approach transforms the network of datasets and claims stored on-chain into an "attestation network," where layered claims underpinning credits have explicit trust signals indicating the author and the parties who have verified or ratified them.

To properly ensure the integrity and traceability of evidence backing Tebu, project actors should prioritize rigorous data management practices. Table 7 outlines the minimum and ideal technical requirements for evidence and claims management in Tebu projects. While the protocol accepts human-readable text claims, it strongly encourages a more rigorous approach using well-defined data schemas in machine-readable formats like JSON-LD. This approach facilitates the transition from high-level, abstract claims to low-level, specific ones, all while maintaining a clear link to supporting evidence.

Table 6. Technical Requirements of Evidence & Claims Management for Tebu Projects

Term	Minimum Technical Requirements	Ideal Technical Requirements
Content of a Claim	List of file types, formats, and specific tables required for all monitoring and verification reports. Details of which claim statements (written in natural language) are required for specific performance standards.	Definitions of machine-readable data formats (in JSON-LD), including schema definitions in either SHACL or JSON Schema, for any claim required for performance standards, as well as all data schemas for all required quantitative information in monitoring & verification reports.
Attestation Metadata	Name and contact information of all individuals and organizations who must author or sign monitoring reports, verification reports, or individual claims.	Cryptographic public keys, or blockchain wallet addresses for any individual or organization who is required to sign or author monitoring reports, verification reports, or individual claims

7.3 *Benefits of a Standards Based Approach*

Adopting a standards-based approach in designing technical infrastructure for Tebu offers significant advantages for storing, anchoring, and attesting data claims. Prioritizing the standardization of data taxonomies, ontologies, schemas, and technical formats converts data and claims into machine-readable formats like JSON, enabling software-based reporting, verification, and machine auditing of claims.

To ensure consistent adoption across organizations and credit protocol developers, it's essential that ecological data claims use not only the same file format but also a standardized vocabulary. This approach mirrors successful standardization efforts in other scientific fields, such as the National Cancer Institute's Harmonized CRDC Model and the Biolink Model for biological knowledge graphs, who accelerated research efforts and made information more accessible across the entire industry.[2,3] Infrastructure built to support auditable ecological claims in biodiversity markets should follow a similar approach, using JSON-LD and leveraging existing data standards where appropriate. This allows for data claims to be queried across organizations, protocols, and institutions, creating a knowledge graph of open ecological data that could be invaluable for climate science research and understanding the relationships between stewardship activities and biodiversity outcomes.

By using JSON-LD and leveraging existing data standards, the Tebu Protocol can create a robust infrastructure for auditable ecological claims in biodiversity markets. This approach enables cross-organizational, cross-protocol, and cross-institutional data querying, potentially revolutionizing our understanding of biodiversity conservation efforts and outcomes.

[2]For more information: https://cancerdhc.github.io/ccdhmodel/v1.1/home/
[3]For more information: https://biolink.github.io/biolink-model/

7.4 *Data Storage, Selective Disclosure, & Privacy in the Tebu Protocol*

While the Tebu Protocol prioritizes transparency and open ecological data, it also recognizes the need for privacy in certain circumstances. Landowners or project developers may require specific documents or claims to remain confidential, shared only on an as-needed basis. To address this balance between transparency and privacy, the protocol leverages the capabilities of the Regen Ledger data module to configure whether datasets are public or private. This approach ensures that datasets can be owned, governed, and controlled by the parties who upload the data. Storage providers can implement various access restrictions, such as limiting access to project documentation data to users who have purchased the project's biodiversity credits, or restricting access to specific monitoring reports or lab test results to authorized third-party verifiers.

To ensure auditability of private datasets, the data module uses Internationalized Resource Identifiers (IRIs) (Michel Suignard et al., 2003). IRIs serve as content hashes that uniquely identify each piece of data, making it traceable and verifiable without revealing the data itself. This system allows stakeholders to verify the authenticity and integrity of data while maintaining its confidentiality.

When submitting a Registration Document for a Tebu project, project developers should clearly outline which datasets and documents are intended for public access and which datasets must be private. For any private data, the Registration Document should detail who will have access to each document and under what conditions (e.g. buyers, 3rd party verifiers, registry operators). This ensures that the project maintains transparency while respecting the confidentiality needs of its stakeholders, such as landowners or technical service providers.

8. GOVERNANCE OF THE TEBU PROTOCOL

8.1 *Addresses, On-Chain Account Management, & Their Relationship to Governance*

Effective management of blockchain accounts is vital for maintaining the integrity and functionality of distributed ledger technology (DLT) systems. The flexibility provided by different blockchain account types supports various organizational structures, enabling effective participation and governance by both individuals and institutions. This section explores different methods for managing blockchain accounts and their importance for governance in the DLT context.

An address on a Distributed Ledger Technology (DLT) platform serves as a unique identifier for an account. Organizational structures behind an address can range from individual users to institutions, and with composability, these addresses can form complex control and governance structures through nested or interconnected setups. Accounts are often used interchangeably with addresses but technically refer to the entities managing roles within the protocol through these addresses. There are various systems to manage these accounts:

- **Individual Accounts and Wallets:** The simplest account management form, individual accounts or wallets, are DLT addresses owned by individuals. They function as the basic identity unit within the protocol, capable of holding currency, sending transactions, or participating in governance. Higher-order account types build upon these individual accounts.

- **Multi-Signature Accounts (Multi-Sigs):** Multi-Sigs enhance security by requiring consensus among multiple users before executing transactions. Controlled by several wallets, these accounts only process transactions when a predefined number of users agree, thereby distributing control and mitigating unauthorized actions. Typically, each participating address in a multi-sig has equal voting power, like a joint bank account requiring multiple signatures for transactions.

- **Group Accounts:** Building on the multi-sig framework, group accounts introduce a layer of hierarchical governance by allowing weighted voting among members. These accounts enable more granular control over decisions and can reflect the varying stakes or roles of members within the group. The Regen Ledger Group Module provides this functionality.[4]

- **Decentralized Autonomous Organizations (DAOs):** Representing the most advanced form of blockchain account management, DAOs operate through autonomous governance structures that can implement a variety of voting systems such as one person, one vote; weighted voting; and token-based voting in which voting weights are influenced by token holdings. DAOs adapt to complex and dynamic governance needs, potentially encompassing multiple levels of sub-groups (sub-DAOS) with specific roles and responsibilities. Due to their composable nature, DAOs can range from simple group approvals to complex organizational structures equivalent to federal governments. Tools like DAODAO and Gnosis Zodiac provide the necessary infrastructure for implementing these advanced governance models.[5,6]

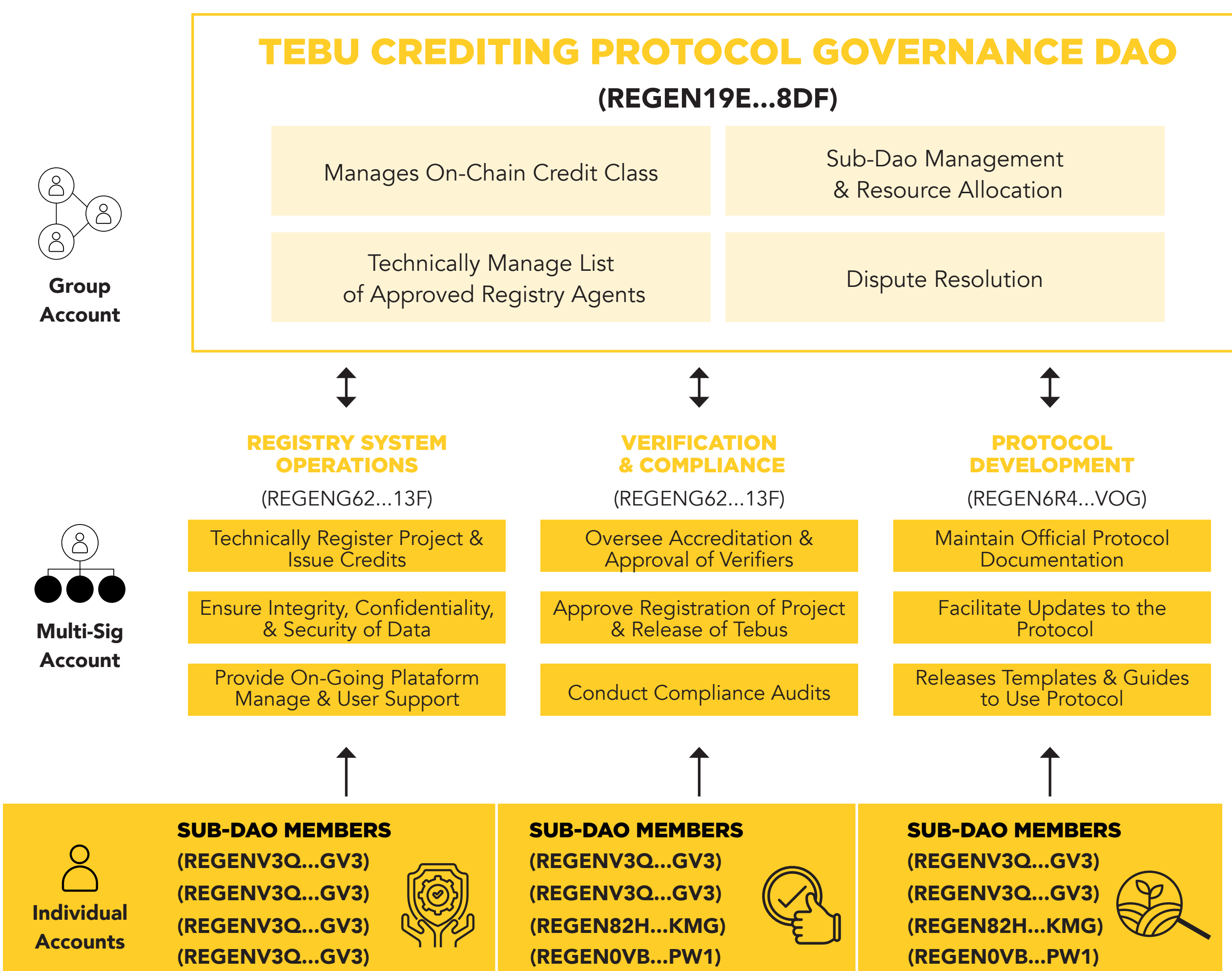
[4]For more information: https://docs.cosmos.network/v0.46/modules/group/
[5]For further detail and information: https://daodao.zone/
[6]For further detail and information: https://github.com/gnosisguild/zodiac

8.2 *How DLT can Improve Governance of the Tebu Protocol*

While the Tebu crediting protocol currently operates without blockchain-based governance structures, leveraging the flexibility of blockchain address management could facilitate smoother management and operations and minimize conflict of interest to ensure greater transparency, accountability, and stakeholder participation in the administration of the crediting process.

Figure 5 visualizes a potential governance model for the protocol using a DAO to decentralize management of different elements of the crediting process. In this scenario, specialized sub-committees, each associated with their own blockchain address, would execute specific responsibilities within the Tebu Protocol. For example, a Protocol Development sub-committee could focus on reviewing and updating scientific procedures and protocol documents, managing an address that stores official documentation. A Verification and Compliance Subcommittee could oversee the approval and monitoring of verifiers, conducting audits to ensure these parties meet required standards.

Figure 5. Example Governance Structure for the Tebu Protocol Using a DAO



Implementing such a system would allow the Tebu protocol to accommodate various governance structures, supporting both centralized and decentralized models as needed. It would provide the technical capability to enforce these structures by assigning specific stakeholders the authority to register projects and issue credits according to predefined rules. The adoption of blockchain-based governance tools could facilitate the inclusion of local communities and enable the establishment of multi-stakeholder oversight committees. These committees could oversee protocol implementation, review audit findings, and make recommendations for improvements. Ultimately, this approach would enhance the protocol's efficiency, transparency, and adaptability to diverse stakeholder needs and evolving best practices in environmental conservation, potentially increasing trust, participation, and effectiveness in biodiversity conservation efforts.

8.3 *Regen Ledger Network Governance & Relationship to the Tebu Protocol*

The adoption of Regen Ledger for the Tebu Protocol necessitates understanding that public governance controls the underlying blockchain infrastructure. Regen Network, like other proof-of-stake blockchains, employs a base layer of governance where token holders decide on core network functionalities.

This governance structure involves voting on software upgrades, which can introduce new features or modify the network. Recent proposals have included the introduction of smart contract capabilities and improvements to group account interfaces.

While this system provides benefits of decentralization and community input, it's crucial for Tebu Protocol stakeholders to actively participate in this governance alongside other community members. This participation empowers co-ownership and control over the platform, allowing the Terrasos community to have a voice in shaping the future direction of the underlying technology that supports the Tebu Protocol. By engaging in network governance, the Terrasos community can help ensure that the evolving capabilities of Regen Ledger align with the needs and vision of biodiversity conservation efforts.

9. LIMITATIONS

9.1

Platform Accessibility

The technical complexities of using DLT to implement and manage the Tebu protocol present accessibility challenges. Key management and domain expertise requirements create significant barriers, potentially excluding the protocol's target audience. The association of DLT with cryptocurrencies may also tarnish its reputation among some stakeholders.

To address these issues, the system requires simplified interfaces for non-technical stakeholders like land stewards, conservation project managers, and financiers. Additionally, Terrasos and partners should provide educational resources and training programs. Hosting hackathons and upskilling initiatives can offer hands-on learning opportunities and foster innovation in biodiversity conservation and make the DLT-based credit system more inclusive and impactful.

9.2

Challenges with Decentralized Network Security

Blockchains such as Regen Ledger, face unique security challenges due to their distributed nature. The Proof of Stake (PoS) implementation of the system risks centralization of network power and wealth over time. Furthermore, the lack of central authority makes coordinated security efforts more complex, as responsibilities are distributed across multiple nodes and participants.

9.3 *Limitations of Decentralized Governance Models*

Decentralized governance models, while offering benefits such as increased transparency and stakeholder participation, also present challenges for the Tebu system. Improper alignment between actors can lead to a slowing pace of innovation or infighting among network members. Poor governance culture may erode network legitimacy, like challenges in democratic systems.

These models can also impede technological progress, especially at the protocol[7] layer. Balancing the legitimacy offered by slow evolution with the need for rapid adaptation to changing circumstances in biodiversity conservation poses a challenge.

To address these limitations, we hope to focus on establishing clear governance frameworks and processes that promote alignment, collaboration, and effective decision-making among stakeholders. Regular communication and engagement with the community can help foster a positive governance culture and ensure that the platform evolves in a manner that benefits all participants. By proactively addressing these challenges, we can create a more resilient and effective decentralized governance model for the Tebu protocol.

10. CONCLUSION

The integration of Distributed Ledger Technology (DLT) into biodiversity crediting systems, as exemplified by the Tebu Protocol, represents a significant leap forward in enhancing the integrity and effectiveness of voluntary biodiversity markets. By leveraging DLT's immutable record-keeping, decentralized governance, and transparent asset tracking abilities to implement advanced registry systems, the Tebu Protocol enables secure, transparent tracking of Tebu throughout their lifecycle. It provides a robust framework for managing ecological claims, enhancing auditability, and fostering trust among stakeholders. While challenges in accessibility and governance persist, the potential benefits of this approach are substantial.

The success of DLT in biodiversity conservation hinges on continued collaboration between technologists, ecologists, policymakers, and local communities. As we refine these systems, we move closer to a more equitable, efficient, and impactful marketplace for biodiversity conservation. This innovation paves the way for a future where technology and ecology converge to create lasting positive impacts on our planet's biodiversity.

[7] A blockchain has 3 layers: protocol, network, and application. In this case, the protocol layer is referenced.

11. BIBLIOGRAPHY

Data Module Concepts | Regen Ledger Documentation. (2022, July 16). https://docs.regen.network/modules/data/01_concepts.html

Ecocredit Module | Regen Ledger Documentation. (2021, October 29). https://docs.regen.network/modules/data/01_concepts.html

Gradeckas, S. (2024, March 25). Deep Dive: Biodiversity credit demand. Bloom Labs. https://sgradeckas.substack.com/p/deep-dive-biodiversity-credit-demand

Open-ended Working Group on the Post-2020 Global Biodiversity Framework. (2022). Draft recommendation submitted by the Co-Chairs. In Open-ended Working Group on the Post-2020 Global Biodiversity Framework. https://www.cbd.int/doc/c/409e/19ae/369752b245f05e88f760aeb3/wg2020-05-l-02-en.pdf

Michel Suignard, Dürst, M. J., & Suignard, M. (2003, January). RFC 3987: Internationalized Resource Identifiers (IRIS). Internet Engineering Task Force Datatracker. https://datatracker.ietf.org/doc/html/rfc3987

Sarmiento, M., Del Valle, E., López, A., Osorio, F., Hincapié Posada, J. E., Vieira Muñoz, M. I., The Nature Conservancy, & Ministerio de Ambiente y Desarrollo Sostenible. (2018). Bancos de habitat: Mecanismo para la implementación de compensaciones bióticas.

Sarmiento, M., Grisales, V., Rodríguez, M. L., Navas, A., Serna, M. (November, 2022). Protocol for Issuing Voluntary Biodiversity Credits V3. www.terrasos.co/wp-content/uploads/20-protocol-for-issuing-voluntary-biodiversity-credits-beta-english.pdf

State of New South Wales (Department of Climate Change, Energy, the Environment and Water). (2011, February 27). Questions and answers about the Biodiversity Banking and Offsets Scheme | NSW Environment, Energy and Science. https://www.environment.nsw.gov.au/biobanking/biobankingqa.htm

United Nations Environment Programme. (2023). State of Finance for Nature: The Big Nature Turnaround – Repurposing $7 trillion to combat nature loss. Nairobi.https://doi.org/10.59117/20.500.11822/44278

TERRASOS

Tebu™
TERRASOS BIODIVERSITY UNIT™

REGEN NETWORK